Objectively Measured Light-Intensity Physical Activity Is Independently Associated With 2-h Plasma Glucose

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OBJECTIVE — We examined the associations of objectively measured sedentary time, light-intensity physical activity, and moderate- to vigorous-intensity activity with fasting and 2-h postchallenge plasma glucose in Australian adults.

RESEARCH DESIGN AND METHODS — A total of 67 men and 106 women (mean age ± SD 53.3 ± 11.9 years) without diagnosed diabetes were recruited from the 2004–2005 Australian Diabetes, Obesity, and Lifestyle (AusDiab) study. Physical activity was measured by Actigraph accelerometers worn during waking hours for 7 consecutive days and summarized as sedentary time (accelerometer counts/min <100; average hours/day), light-intensity (counts/min 100-1951), and moderate- to vigorous-intensity (counts/min ≥1,952). An oral glucose tolerance test was used to ascertain 2-h plasma glucose and fasting plasma glucose.

RESULTS — After adjustment for confounders (including waist circumference), sedentary time was positively associated with 2-h plasma glucose ($b = 0.29$, 95% CI 0.11–0.48, $P = 0.002$); light-intensity activity time ($b = -0.25$, −0.45 to −0.06, $P = 0.012$) and moderate- to vigorous-intensity activity time ($b = -1.07$, −1.77 to −0.37, $P = 0.003$) were negatively associated. Light-intensity activity remained significantly associated with 2-h plasma glucose following further adjustment for moderate- to vigorous-intensity activity ($b = -0.22$, −0.42 to −0.03, $P = 0.023$). Associations of all activity measures with fasting plasma glucose were nonsignificant ($P > 0.05$).

CONCLUSIONS — These data provide the first objective evidence that light-intensity physical activity is beneficially associated with blood glucose and that sedentary time is unfavorably associated with blood glucose. These objective data support previous findings from studies using self-report measures, and suggest that substituting light-intensity activity for television viewing or other sedentary time may be a practical and achievable preventive strategy to reduce the risk of type 2 diabetes and cardiovascular disease.

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Chronic high blood glucose concentrations (hyperglycemia) are both a characteristic and a precursor of type 2 diabetes (1). Hyperglycemia is also associated with an increased risk of cardiovascular disease and premature mortality, and this association persists below the categorical cutoffs for diabetes and impaired glucose tolerance (2–5). Understanding the association of modifiable type 2 diabetes risk factors with blood glucose across the glucose range can inform the development of population strategies for reducing the risk of diabetes and other cardiovascular diseases.

Physical activity is one of the key modifiable risk factors for hyperglycemia. Evidence from population-based cross-sectional studies indicates that both physical activity and sedentary behavior (particularly television viewing time) are independently associated with blood glucose in adults without known diabetes (6–8). However, the physical activity and sedentary time variables in these studies have typically been derived from self-report measures, generally a 1-week recall. In addition to the imprecision associated with such measures, it is also difficult to accurately capture light-intensity physical activity or total sedentary behavior (rather than components of leisure-time sedentary behavior) by questionnaire (9). Light-intensity activity, which includes activities such as washing dishes, ironing, and other routine domestic or occupational tasks (10), is the predominant determinant of variability in total daily energy expenditure (11). Clinical studies have demonstrated associations between nonexercise activities ("nonexercise activity thermogenesis") and obesity risk (12); however, there is limited evidence on the extent to which such light-intensity activities are associated with other health outcomes (13,14).

Given the challenge of assessing physical activity across the continuum of varying intensities, accurate measures of free-living physical activities (sedentary, light, moderate, and vigorous) are required. Using accelerometers, we examined the associations of objectively measured sedentary time, light-intensity activity, and moderate- to vigorous-intensity activity with fasting and 2-h postchallenge plasma glucose in Australian adults without diagnosed diabetes.

RESEARCH DESIGN AND METHODS

— Participants for this cross-sectional observational study were recruited between October and December 2005 from attendees at five Queensland testing sites of the population-based Australian Diabetes, Obesity and Lifestyle (AusDiab) Study (15–17). Recruitment for the present study was contingent on accelerometer availability and the timing

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Abbreviations: AusDiab; Australian Diabetes, Obesity, and Lifestyle; FPG, fasting plasma glucose.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—*Sex-specific demographic, biological, physical activity, and behavioral characteristics of study participants*

Characteristic	Men	Women	Total	*P* for sex difference
n	67	106	173	
Age (years)	52.7 (49.7–55.7)	53.6 (51.4–55.9)	53.3 (51.5–55.1)	0.628
BMI (kg/m^2)	27.8 (26.8–28.7)	26.8 (25.9–27.8)	27.2 (26.5–27.9)	0.187
Waist circumference (cm)	98.2 (95.6–100.9)	87.0 (84.8–89.2)	91.4 (89.5–93.2)	<0.001
Height (cm)	176.3 (175.0–177.6)	163.4 (162.1–164.6)	168.4 (167.1–169.7)	<0.001
FPG (mmol/l)	5.4 (5.2–5.5)	5.1 (5.0–5.2)	5.2 (5.1–5.3)	<0.001
2-h plasma glucose (mmol/l)	6.0 (5.5–6.5)	5.6 (5.3–5.8)	5.7 (5.5–6.0)	0.055
Plasma glucose status				
Normal glucose tolerance	53 (79)	96 (91)	149 (86)	
Isolated IFG	1 (2)	1 (1)	2 (1)	
Isolated IGT	9 (13)	8 (8)	17 (10)	
IFG and IGT	1 (2)	1 (1)	2 (1)	
Newly diagnosed diabetes	3 (5)	0 (0)	3 (2)	
Accelerometer-derived variables (average daily time in h)				
Time accelerometer worn	14.8 (14.5–15.1)	14.8 (14.6–15.1)	14.8 (14.6–15.0)	0.840
Sedentary time*	8.5 (8.2–8.8)	8.3 (8.1–8.6)	8.4 (8.2–8.6)	0.283
Light-intensity activity*	5.6 (5.3–6.0)	6.1 (5.8–6.3)	5.8 (5.7–6.0)	0.045
Moderate- to vigorous-intensity activity*	0.7 (0.6–0.8)	0.5 (0.4–0.5)	0.6 (0.5–0.6)	<0.001
Moderate- to vigorous-intensity activity by accelerometer and diary*	0.8 (0.7–0.9)	0.5 (0.5–0.6)	0.6 (0.6–0.7)	<0.001
Percent time at each activity level while accelerometer worn (%)				
Sedentary time	57.2 (54.9–59.5)	55.9 (54.2–57.6)	56.6 (55.2–58.0)	0.328
Light-intensity activity	23.0 (21.7–24.3)	24.5 (23.5–25.5)	23.8 (23.0–34.6)	0.063
Moderate- to vigorous-intensity activity	4.5 (4.0–5.1)	3.2 (2.8–3.6)	3.9 (3.5–4.2)	<0.001
Moderate- to vigorous-intensity activity by accelerometer and diary	5.2 (4.5–5.8)	3.5 (3.1–4.0)	4.3 (4.0–4.7)	<0.001
Current smokers	1 (2)	2 (2)	3 (2)	0.828
Family history of diabetes	11 (16)	28 (26)	39 (22)	0.130
University/further education	44 (66)	52 (49)	96 (56)	0.038
Moderate/heavy alcohol drinkers	30 (45)	24 (3)	54 (31)	0.007
Full-time employment	53 (79)	42 (40)	95 (55)	<0.001
Household income ≥$1500/week	35 (52)	32 (30)	67 (39)	0.005

Data are means (95% CI) or *n* (%). *Means adjusted for time accelerometer worn; statistical comparisons are adjusted for age. Sedentary time (<100 counts/min), light-intensity activity (100–1,951 counts/min), and moderate- to vigorous-intensity activity (≥1,952 counts/min). IFG, impaired fasting glucose; IGT, impaired glucose tolerance.

of examination procedures of the main study; those with known diabetes, with visible limitations to mobility, and pregnant women were not approached. Of those available and eligible, all were approached, with the recruitment rate exceeding 80% at each site. Each participant gave informed consent to participate, and ethics approval was obtained from the International Diabetes Institute and from the University of Queensland.

On the day of recruitment, participants underwent biochemical, anthropometric, and behavioral assessments as part of the larger set of AusDiab survey procedures. The detailed methods of this protocol have been previously published (16–18). In brief, following an overnight fast (minimum of 9 h), an oral glucose tolerance test was performed using World Health Organization specifications (19). The outcome variables of fasting plasma glucose (FPG) and 2-h plasma glucose levels were determined by a spectrophotometric-hexokinase method (Roche Modular; Roche Diagnostics, Indianapolis, IN). Demographic and behavioral attributes were assessed using interviewer-administered questionnaires; height, weight, and waist circumference were measured.

Uniaxial Actigraph accelerometers (formerly known as the CSA activity monitor model WAM 7164; http://www.theactigraph.com/), fitted firmly around the participant's trunk and placed on the right anterior axillary line, were used to measure physical activity. Participants were instructed to wear the accelerometer during all waking hours for a continuous period of 7 days and to provide details on activity duration, type, and intensity during nonwearing/nonsleep periods. Physical activity diaries supplemented the accelerometer data by recording nonambulatory activities as well as on/off times of the accelerometer.

Statistical analysis

In line with previous research reporting the reliability and validity of the International Physical Activity Questionnaire (20), a pragmatic cutoff of <100 counts/min was chosen to categorize sedentary

Table 2—*Regression analysis of physical activity measures with 2-h postchallenge plasma glucose*

	B	95% CI	*P*	Adjusted R^2
Model 1				
Sedentary time	0.35	0.17 to 0.53	<0.001	0.13
Light-intensity activity	−0.30	−0.49 to −0.12	0.002	0.11
Moderate- to vigorous-intensity activity	−1.08	−1.76 to −0.41	0.002	0.11
Model 2				
Sedentary time	0.29	0.11 to 0.48	0.002	0.16
Light-intensity activity	−0.25	−0.45 to −0.06	0.012	0.14
Moderate- to vigorous-intensity activity	−1.07	−1.77 to −0.37	0.003	0.15
Model 3				
Sedentary time*	0.23	0.04 to 0.42	0.019	0.18
Light-intensity activity*	−0.22	−0.42 to −0.03	0.023	0.17
Moderate- to vigorous-intensity activity†	−0.81	−1.53 to −0.09	0.029	0.18
Model 4 (sex interactions; male ref.)				
Sedentary time	−0.22	−0.52 to 0.08	0.148	0.16
Light-intensity activity	0.27	−0.13 to 0.66	0.181	0.14
Moderate- to vigorous-intensity activity	0.52	−0.81 to 1.84	0.445	0.15

Activity measured as hours per day. Model 1 was adjusted for age, sex, and time accelerometer worn. Model 2 was adjusted for age, sex, height, waist circumference, time accelerometer worn, accelerometer unit, family history of diabetes, alcohol intake, education, income, and smoking status. Model 3 was adjusted for above covariates and moderate-to-vigorous physical activity (*) or sedentary time (†). Model 4 was adjusted for the same covariates as Model 2 and examined the sex interaction.

time, which includes activities such as sitting or working quietly (e.g., reading, typing). The widely utilized Freedson's cutoffs (21) were then used to differentiate moderate- to vigorous-intensity activity (counts/min ≥1,952) from light-intensity activity (100–1,951 counts/min). A criterion of at least 20 min of continuous 0 counts, as well as diary information, identified nonwearing periods. Average daily time (h) was used to summarize the time spent in moderate- to vigorous-intensity, light-intensity, and sedentary activity.

To be included in the analysis, participants were required to wear the accelerometer for at least 5 valid days, including at least 1 weekend day, where a valid day was at least 10 h of recorded activity (using both accelerometer and diary data). Of the 204 originally recruited, there were 9 withdrawals, 6 cases where the accelerometer download was faulty and 11 cases where the participant did not meet the compliance criteria, leaving a total of 178 (70 men, 108 women) who met the inclusion criteria. Blood glucose measures were available for 173 of these participants (67 men, 106 women). Data were complete for all other variables. Of the 173, 6 (3.5%) had 5 days of valid physical activity data, with the majority (80.3%) having 7 days of valid data.

Univariate analyses were used to compare sex differences for descriptive and physical activity characteristics of the sample. Forced-entry linear regression models then examined the associations of physical activity with blood glucose measures. Models were initially adjusted for the potential confounders of age (years), sex, and time accelerometer worn (h), with further adjustment for height (cm), waist circumference (cm), accelerometer unit number, alcohol intake (self-reported as none, light, and moderate-to-heavy), education (attended university or further education, yes/no), income (household income ≥$1,500/week, yes/no), smoking status (current or ex/nonsmoker), and family history of diabetes (8). Sex and age (<60 and ≥60 years) differences in the associations between the physical activity and blood glucose measures were tested for by adding interaction terms to the model. Statistical significance was set at $P < 0.05$ for the main effects, and $P < 0.1$ for the interaction effects. Analyses were conducted using Stata version 9.0 (22).

RESULTS — The age of the participants ranged from 30 to 87 years (mean 53.3 years), and the majority (86%) had blood glucose readings within the "normal" range (<6.1 mmol/l for FPG and <7.8 mmol/l for 2-h plasma glucose); 47.4% were overweight (BMI 25.0–29.9 kg/m^2), and 21.4% were obese (BMI ≥30 kg/m^2). The majority (98.8%) spoke English at home, while 38 women (35.5%) had either gone through or were now going through menopause. Sociodemographic and behavioral characteristics are listed in Table 1.

Consistent with previous findings (1,7,8), men had significantly higher FPG readings and waist circumference and spent more time in moderate- to vigorous-intensity activity compared with women. Additionally, a higher proportion of men worked full-time compared with women. Compared with the broader AusDiab Study population, participants in this substudy were slightly younger (53.0 vs. 56.6 years, $P < 0.001$) but had a similar mean BMI (27.2 vs. 27.7 kg/m^2, $P = 0.683$), self-reported physical activity (5.2 vs. 4.8 h/week, $P = 0.372$), and self-reported television viewing time (13.3 vs. 13.7 h/week, $P = 0.628$).

Table 2 shows that after adjustment for potential confounders, higher sedentary time was associated with significantly higher 2-h plasma glucose, while higher moderate- to vigorous-intensity and increased light-intensity physical activity time were associated with significantly lower 2-h plasma glucose. Although attenuated, these significant associations persisted after adjusting for other physical activity measures. Figure 1 highlights these significant adjusted associations with 2-h plasma glucose across sex-specific quartiles of sedentary time, light intensity, and moderate- to vigorous-intensity physical activity.

The significant association of moderate- to vigorous-intensity physical activity with 2-h plasma glucose persisted when

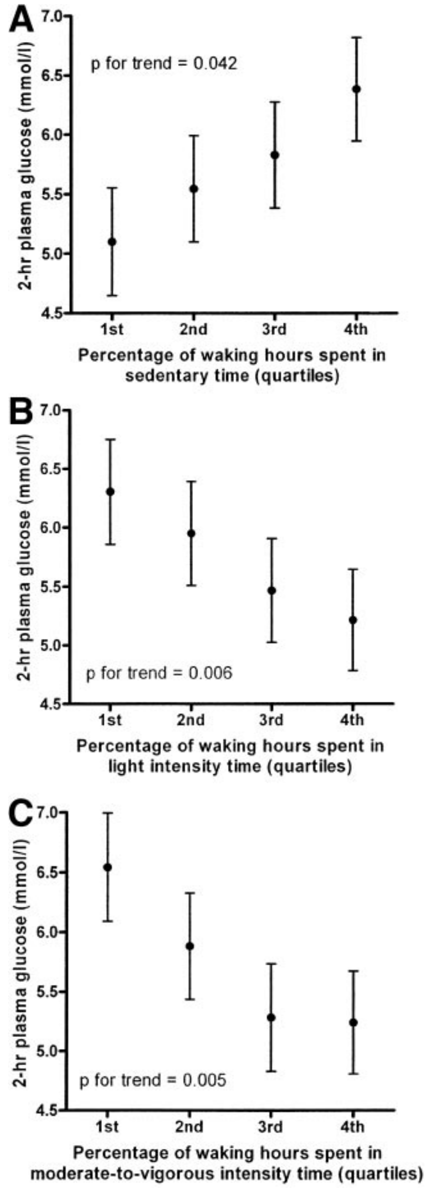

Figure 1—*Associations of 2-h plasma glucose with quartiles of percentage of waking hours spent in sedentary time* (A)*, light-intensity activity* (B)*, and moderate- to vigorous-intensity activity* (C). A: *The cut points for men were 51.19, 58.44, and 64.05; for women, they were 51.05, 55.55, and 62.85.* B: *The cut points for men were 19.26, 22.65, and 26.27; for women, they were 20.19, 24.47, and 27.54. C: The cut points for men were 2.94, 5.03, and 6.96; for women, they were 1.90, 2.91, and 4.72. Marginal means (95% CI) were adjusted for age, sex, height, waist circumference, family history of diabetes, alcohol intake, education level, income, smoking status, accelerometer unit, and percent moderate- to vigorous-intensity activity (sedentary and light intensity) or percent sedentary (moderate to vigorous intensity).*

the diary data were excluded from the analysis ($b = -1.07$ [95% CI -1.86 to -0.28] $P = 0.008$). Additionally, although attenuated, the direction of the effect remained the same when only those with 7 days of complete data were analyzed ($n = 139$), with nonstandardized regression coefficients of 0.17 ($P = 0.088$), -0.14 ($P = 0.162$), and -0.42 ($P = 0.271$) for sedentary time, light-intensity activity, and moderate- to vigorous-intensity activity, respectively. A similar pattern was also observed when a more generalized measure of obesity, BMI, was included in the models instead of waist circumference, with nonstandardized regression coefficients of 0.31 ($P = 0.001$), -0.27 (0.006), and -1.09 (0.002) for the three intensity levels (sedentary time, light, and moderate to vigorous, respectively). Similarly, when the data were reanalyzed for full-time workers only ($n = 95$), the nonstandardized regression coefficients were 0.32 ($P = 0.018$), -0.28 ($P = 0.064$), and -1.09 ($P = 0.014$) for sedentary time, light-intensity activity, and moderate- to vigorous-intensity activity, respectively.

For FPG, Table 3 shows that the only significant association observed was with sedentary time, adjusted for age, sex, and time accelerometer worn. However, the association became nonsignificant following further adjustment for potential confounders, including waist circumference. There were no statistically significant sex or age interactions observed for the associations between the physical activity measures and blood glucose ($P > 0.1$).

CONCLUSIONS — Previous research in this study population has reported significant dose-response associations of sedentary behavior (television viewing time) and moderate-to-vigorous physical activity with 2-h plasma glucose, but not FPG, using self-report measures (6,8). Our study extends these findings and is the first to examine the associations of objectively measured intensity of physical activity and sedentary time with blood glucose measures in adults. Following adjustment for potential confounders, including waist circumference, significant dose-response associations of sedentary time and moderate- to vigorous-intensity physical activity were observed with 2-h plasma glucose, but not FPG, with the magnitude of the associations greater than that previously reported (6,8,23). Given that the characteristics of our sample are similar to the participant characteristics of the overall AusDiab sample, these results increase our confidence in earlier findings that were based on self-reported physical activity and sedentary behavior (6,8,18).

A major finding of this study is the significant association of light-intensity physical activity with 2-h plasma glucose, independent of moderate- to vigorous-intensity physical activity time. Light-intensity physical activities are reported to be the most prevalent form of activity in the general North-American population; however, this intensity level is particularly difficult to detect and assess (9). Consequently, there is limited epidemiological evidence on the association between light-intensity physical activity and health outcomes (13,14). The majority of participants in our study had normal glucose tolerance and, therefore, would be considered to have a lower risk for hyperglycemia-induced complications compared with those with impaired glucose tolerance. However, a recent meta-analysis of 38 prospective studies reported a continuous linear association between increasing 2-h plasma glucose and risk of all-cause and cardiovascular disease mortality, with no apparent risk threshold (4). Thus, even apparently small shifts in 2-h plasma glucose may have important clinical implications.

On average, participants spent only a small proportion of waking hours in moderate- to vigorous-intensity activity (4%). Most activity during waking hours can thus be categorized broadly into two distinct modes: light-intensity physical activity and sedentary time. Those who spend more time in light-intensity activity must therefore spend less time in sedentary behaviors. The beneficial association of light-intensity physical activity with 2-h plasma glucose, as opposed to the detrimental association of sedentary time with 2-h plasma glucose, has important implications for lifestyle interventions. Although moderate- to vigorous-intensity physical activity is an important component of the healthy lifestyle message, practically, intervention studies that target reducing sedentary behavior by the substitution of light-intensity activities may have a higher success rate, particularly given that more than one-half of the population fails to participate in adequate amounts of physical activity to benefit their health (6). Light-intensity physical activity interventions may also be more likely to succeed across a variety of settings, including the workplace.

The only significant association observed for FPG was for sedentary time, unadjusted for waist circumference. This concurs with previous population-based research using self-reported television

Table 3—*Regression analysis of physical activity measures with fasting plasma glucose*

	B	95% CI	*P*	Adjusted R^2
Model 1				
Sedentary time	0.05	0.00 to 0.11	0.046	0.13
Light-intensity activity	−0.04	−1.00 to 0.11	0.117	0.12
Moderate- to vigorous-intensity activity	−0.15	−0.35 to 0.05	0.141	0.12
Model 2				
Sedentary time	0.04	−0.02 to 0.09	0.163	0.15
Light-intensity activity	−0.03	−0.09 to 0.02	0.248	0.15
Moderate- to vigorous-intensity activity	−0.08	−0.29 to 0.13	0.439	0.15
Model 3				
Sedentary time*	0.04	−0.02 to 0.09	0.224	0.15
Light-intensity activity*	−0.03	−0.09 to 0.03	0.281	0.15
Moderate- to vigorous-intensity activity†	−0.04	−0.26 to 0.09	0.706	0.15
Model 4 (sex interactions; male ref.)				
Sedentary time	−0.03	−0.12 to 0.06	0.549	0.15
Light-intensity activity	0.03	−0.09 to 0.15	0.613	0.15
Moderate- to vigorous-intensity activity	0.03	−0.37 to 0.42	0.898	0.14

Activity measured as hours per day. Model 1 was adjusted for for age, sex, and time accelerometer worn. Model 2 was adjusted for age, sex, height, waist circumference, time accelerometer worn, accelerometer unit, family history of diabetes, alcohol intake, education, income, and smoking status. Model 3 was adjusted for above covariates and moderate-to-vigorous physical activity (*) or sedentary time (†). Model 4 was adjusted for the same covariates as Model 2 and examined the sex interaction.

time as an estimate of sedentary behavior (7,8,24). These findings emphasize the important physiological differences between FPG and 2-h plasma glucose in their relationship with physical activity and highlight that lifestyle interventions addressing increasing physical activity and reducing sedentary time need to measure 2-h plasma glucose, rather than FPG, as the primary outcome.

This is the first study to examine associations of objectively assessed intensity of free-living physical activity and sedentary time with standard blood glucose measures. The study was conducted in a nonclinical population that was representative of the broader AusDiab study population. Additional strengths of the study include the detailed sociodemographic, medical, and behavioral data obtained. There was high compliance with the study protocol, and the study followed recommendations for best practice for the use of accelerometers in field work (25). Measurement of physical activity and sedentary time was not limited to leisure-time activities, while the combined use of accelerometers and physical activity diaries ensured that a broad range of physical activities could be captured and analyzed.

There are some potential limitations of our findings. The cross-sectional nature of the data limits inference about causality, though considering that those with known diabetes were excluded from the study, it is unlikely that the blood glucose levels of our participants could have influenced their physical activity behavior. The 7-day collection of physical activity data occurred after the blood glucose measure was taken. Given that there are acute effects of physical activity on blood glucose, the results of this study are therefore reliant on the extent to which participants engaged in a typical week of free-living physical activity behavior. Additionally, the beneficial association of moderate-to-vigorous physical activity on 2-h plasma glucose may have been underestimated, as placing moderate- to vigorous-intensity physical activity into a single category does not take into account the strong influence on insulin action of vigorous-intensity activity compared with moderate-intensity activity (26). Limitations are inherent in all cut points used to summarize accelerometer data (27). Freedson's cut points were used in this study, and although they are one of the more commonly reported cut points used in accelerometer studies of physical activity, they were originally derived using a young adult population (21), and the intensity values that represent light and moderate-to-vigorous may not reflect the self-reported intensity level in this older adult population. Similarly, in line with previous research (20), a relatively high cut point of <100 counts/min was chosen for sedentary time. Although it is unlikely to change the direction of the findings, a lower cut point for sedentary time may be more appropriate, given the recent evidence that nonambulatory standing activities, such as the filing of paperwork, can register a quite low average of 60 counts/min (28). Also, there is some evidence that the relationship between accelerometer counts and physical activity intensity varies across individuals (29). Future research, using shorter epoch lengths, should utilize recently published regression equations that more accurately capture free-living physical activity (28).

Our study adds to the broader evidence base on not only the importance of increasing moderate-to-vigorous physical activity but also reducing sedentary behavior in adult populations where the prevalence of type 2 diabetes is increasing. Our data provide the first objective evidence that light-intensity physical activity is beneficially associated with blood glucose and that sedentary time is unfavorably associated with blood glucose. Substituting light-intensity activity for television viewing or other sedentary time may be a practical and achievable preventive strategy.

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